Collisional energy loss and the suppression of high p_T hadrons

Jan-e Alam[a], Abhee K. Dutt-Mazumder[b] and Pradip Roy[b]

[a]Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata 700 064, India

[b]Saha Institute of Nuclear Physics, 1/AF Bidhan Nagar, Kolkata 700 064, India

We calculate nuclear suppression factor (R_{AA}) for light hadrons by taking only the elastic processes and argue that in the measured p_T domain of RHIC, collisional rather than the radiative processes is the dominant mechanism for partonic energy loss.

1. Introduction

Jet quenching is one of the most promising tools to extract the initial parton density produced in high energy heavy ion collisions [1]. This is related to the final state energy loss of the leading partons causing depopulation of hadrons [2] at high transverse momentum (p_T). The suppressions of high p_T hadrons and unbalanced back-to-back azimuthal correlations of the dijet events in Au+Au collisions measured at Relativistic Heavy Ion Collider (RHIC) provide experimental evidence in support of the quenching. The observed nuclear suppression of light hadrons (π, η) in $Au + Au$ collisions at $\sqrt{s} = 62 - 200$ A GeV at RHIC was reproduced by radiative loss only assuming that the contributions from collisional loss is negligible. However, the non-photonic single electron spectrum from heavy meson decays measured by PHENIX Collaboration [3] put this assumption in question. No realistic parameter set can explain this data using the radiative energy loss based jet tomography model which either requires violation of bulk entropy bounds or non-perturbatively large α_s of the theory [4], or equivalently one requires excessive transport co-efficient $\hat{q}_{\text{eff}} = 14$ GeV^2/fm [5].

In this light, we, in the present work would like to address if the omission of collisional loss at RHIC is justified or not. We argue that, whether the collisional or radiative loss is the main mechanism of energy dissipation, is a p_T dependent question. It also depends on the energies of the colliding system and expected to be different for RHIC and Large Hadron Collider (LHC). In contrast to the previous works, we calculate nuclear suppression factor for pions at RHIC energy considering only the collision energy loss.

The partonic energy loss due to collisional processes was revisited in [6] and its importance was demonstrated in the context of RHIC in[7]. It is shown in ref.[6] that there exists an energy range where collisional loss is as important as or even greater than its radiative counter part, hence cannot be neglected in any realistic model of jet quenching. Recently this is also noted in ref.[4, 8].

2. Formalism

We use Fokker Planck (FP) equation to dynamically evolve parton spectra. FP equation can be derived from Boltzmann equation if one of the partner of the binary collisions is in thermal equilibrium and the collisions are dominated by the small angle scattering involving soft momentum exchange [7, 9, 10, 11]. For a longitudinally expanding plasma, FP equation reads:

$$\left(\frac{\partial}{\partial t} - \frac{p_\parallel}{t}\frac{\partial}{\partial p_\parallel}\right) f(\mathbf{p},t) = \frac{\partial}{\partial p_i}[p_i\eta f(\mathbf{p},t)] \quad + \frac{1}{2}\frac{\partial^2}{\partial p_\parallel^2}[B_\parallel(\mathbf{p})f(\mathbf{p},t)] \quad + \frac{1}{2}\frac{\partial^2}{\partial p_\perp^2}[B_\perp f(\mathbf{p},t)] \quad (1)$$

where the second term on the left hand side arises due to expansion [12]. Bjorken hydrodynamical model [13] has been used here for space time evolution. In Eq. (1), $f(\mathbf{p},t)$ represents the non-equilibrium distribution of the partons under study, $\eta = (1/E)dE/dx$, denotes drag coefficient, $B_\parallel = d\langle(\Delta p_\parallel)^2\rangle/dt$, $B_\perp = d\langle(\Delta p_\perp)^2\rangle/dt$, represent diffusion constants along parallel and perpendicular directions of the propagating partons.

In our calculations we include some of the important features which were ignored in previous work [14] in the context of jet quenching. These are: (i) the term corresponding to the longitudinal expansion is included, (ii) the momentum evolution of parton distributions both along longitudinal and transverse direction is considered and (iii) the mechanism of hadronization is introduced.

The transport coefficients, η, $B_\parallel$ and $B_\perp$ appeared in eq.(1) have been calculated in Ref. [7]. The FP equation has been solved for the initial parton distributions parametrized as [15]:

$$f(p_T, p_z, t = t_i) \equiv \frac{dN}{d^2p_T dy}\big|_{y=0} = \frac{N_0}{(1 + \frac{p_T}{p_0})^\alpha}, \quad (2)$$

where $p_0 = 1.75$, $\alpha = 8$. Since asymptotically the multiplicity of any hadron species produced by a gluon jet is 9/4 times that of quark [16], the normalization constant N_0 for gluons is chosen accordingly. Solving the FP equation with the boundary conditions, $f(\vec{p},t) \to 0$ for $|p| \to \infty$, we evaluate the nuclear suppression factor, R_{AA} defined as,

$$R_{AA}(p_T) = \frac{\sum_a \int f_a(\mathbf{p}',\tau_c)|_{p'_T=p_T/z}D_{a/\pi^0}(z,Q^2)dz}{\sum_a \int f_a(\mathbf{p}',\tau_i)|_{p'_T=p_T/z}, D_{a/\pi^0}(z,Q^2)dz} \quad (3)$$

where $f(\mathbf{p}',\tau_i)$ and $f(\mathbf{p}',\tau_c)$ denote the parton distributions at proper time τ_i and τ_c respectively. Here τ_i is the initial time and τ_c is the time when the system cools down to the transition temperature T_c (=190 MeV). We have taken $\alpha_s = 0.3$ and the initial temperature $T_i = 450$ MeV.

3. Results

The result of our calculations for neutral pion is shown in Fig. 1 which describes the PHENIX data[17] for $Au + Au$ at $\sqrt{s} = 200$ GeV reasonably well. To stress our point further we also analyse the excitation function of the nuclear suppression factor. This has recently been studied in [18] attributing the suppression mechanism to radiative loss.
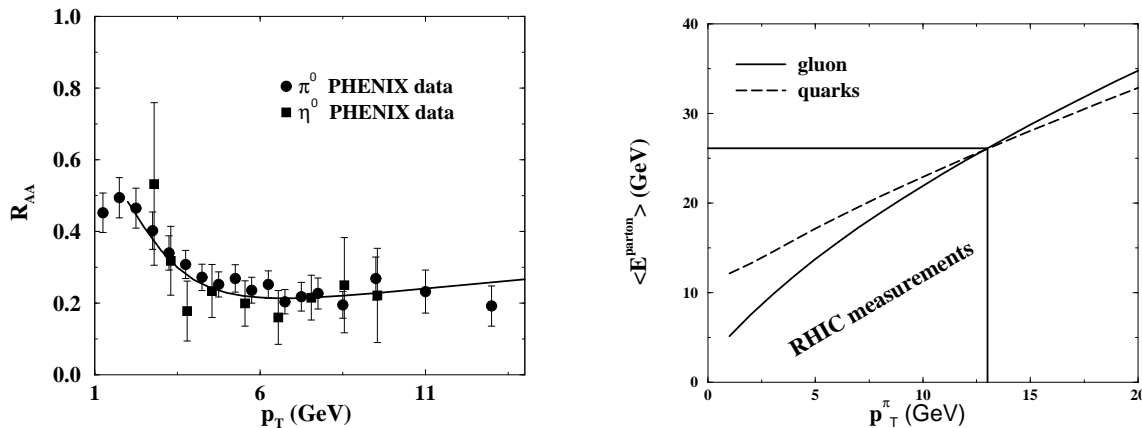
Figure 1. Nuclear suppression factor for pion. Experimental data are taken from PHENIX collaboration [17] for Au + Au collisions at $\sqrt{s} = 200$ GeV. Solid line indicates result from the present calculation with collisional energy loss of the partons propagating through the plasma before fragmenting into pions.

Figure 2. Average parton energy versus transverse momentum of pion for $\sqrt{s} = 200$ GeV/A.

As at lower $\sqrt{s}$, collisional loss wins over its radiative counter part, we reanalyze the excitation function with the former and reproduce the data well [19].

To pin down the relative importance of $2 \leftrightarrow 2$ and $2 \rightarrow 3$ processes, we determine the average energy of the parton which contribute to the measured p_T window of the hadrons. The average fractional momentum, $\langle z \rangle$ of the fragmenting partons carried by the pion is calculated using relevant parton distribution and fragmentation functions, i.e. $\langle z \rangle \propto \int dz z \{ f(x_a, Q^2) f(x_b, Q^2) D_{a \rightarrow h}(z, Q^2) + f(x_b, Q^2) f(x_a, Q^2) D_{b \rightarrow h}(z, Q^2) \}$. For the parton distributions, we use CTEQ [20] including shadowing *via* EKS98 parametrization[21], while for the fragmentation function KKP parametrization is used [22]. The average energy of the parton, $\langle E^{\mathrm{parton}} \rangle$ is obtained by using the relation $< E^{parton} >= p_T^\pi / < z >$ for $y_\pi = 0$. The results are shown in Fig. 2.

It might be recalled that at RHIC energies the nuclear modification factor $R_{AA}(p_T)$ has been measured in the pion transverse momenta range $p_T \sim 1 - 13$ GeV. Assuming that these pions are originated from the fragmenting partons it is clear that the maximum average parton energy required is about 26 GeV here. We might compare this value with the determined E_c[1] given in ref. [6] and note that at these energies collisional loss cannot be neglected. For lower beam energy, 62.4 (130) A GeV the value of maximum average parton energy required to produce a 13 GeV pion is 16 (22) GeV, where the collisional loss will definitely be more important.

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[1]Note that E_c is defined to be the energy below which elastic loss dominates [6].

4. Summary

In conclusion, our investigations clearly suggest that in the measured p_T range of light hadrons at RHIC collisional, rather than the radiative, is the dominant mechanism of jet quenching. Inclusion of three body elastic channels might even increase E_c making our point stronger.

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